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Operant Detection of Extremely Low Frequency Magnetic Fields by the Domestic Pigeon *Columba livia*

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C.G. BLOMME, G.H. PARKER and M.A. PERSINGER. 1990. Operant detection of extremely low frequency magnetic fields by the domestic pigeon *Columba livia*. *Bird Behaviour* **8**: 73-78.
Using a double disc discrimination method, four pigeons were trained to discriminate the presence of a weak rotating magnetic field during the first few minutes of each test session. In addition, the birds were exposed to this paradigm during periods when the test chamber was dark or illuminated by overhead lighting. Only one pigeon showed strong indications of protracted accurate discrimination between the presence or absence of rotating magnetic fields. The other pigeons showed some evidence of learning that often required more than two weeks of training. However, the predominant behavioural pattern suggested that stereotyped (i.e., preference) responding to a particular lever was more probable than true discrimination. When discrimination of the field did occur it was easily disrupted by sudden changes in chamber lighting during testing.

Pigeon *Operant* *Magnetic field* *Discrimination*

Introduction

It has been historically difficult to show the ability of birds to detect a magnetic field (6, 11). Recent pigeon studies attempting to show magnetic field detection in the laboratory have found predominately negative results (1, 4, 8, 9). Bookman's (3) study suggested that fluttering behaviour may be necessary for magnetic field detection. To simulate this condition we exposed pedigree pigeons to a low frequency, rotating magnetic field.

The question of whether animals can discriminate magnetic fields has been complicated by methodology issues. However, procedures that have been used in pharmacology may reduce these diffiiculties. In a classic study, Appel *et al.* (2) found that rats administered different classes of drugs could learn to discriminate their effects. If a certain drug were given, the rats were rewarded when they pressed lever A but not lever B. If a saline solution were given, the rats were rewarded when they pressed lever B but not lever A. Bar A and bar B were associated with separate physiological effects.

In principle, this procedure is optimal for the detection of weak environmental stimuli such as rotating magnetic fields. It was reasoned that weak magnetic fields (<1 Gauss) might become discriminable cues if they were associated with reward. When the magnetic fields were present, the pigeon would be rewarded for pecking disc A but not B. If the fields were not present, the pigeon would be rewarded for pecking disc B but not A. In essence, the field would substitute for the reference drug.

Materials and Method

Subjects

Five pigeons (numbered 747, 743, 728, 670, and 759) of known homing stock were acquired as fledgings. Four birds were used as test subjects while one (759) was used as a weight reference control.

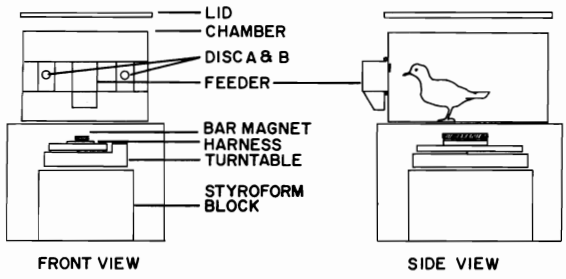

Figure 1. Diagram of the experimental apparatus showing chamber,turntable, bar magnet and pigeon. The two discs and feeder are connected to the outside of the plexiglass sheet.

Apparatus

A test training chamber, measuring 48 cm long x 38 cm high x 39 cm wide was constructed of 6 mm thick plexiglass. The feeder and discs were attached to two parallel threaded rods at one end of the chamber (see Figure 1). Disc A and disc B were placed at pigeon head height (15 cm) and 7 cm from the side walls. The chamber was placed on a large wooden platform 70 cm above the floor. Directly underneath the chamber and centred towards the feeding area was a turntable that was used to apply low intensity magnetic fields on training and test days. Power sources, recorder and recording devices were wired to another room so they would not influence the response patterns of the bird during testing.

General Procedure

An in-line switch made it possible to reinforce the bird (by activating the feeder) through either disc A or disc B. A cumulative recorder was used to tally daily reinforcement responses. Birds were tested daily for 15 min. They were taught to respond to a FR (Fixed Ratio) 20 schedule with 3 s of reinforcement. The FR 20 schedule meant that twenty correct responses would result in one reinforcement. The numbers of depressions of the reinforcement disc and non-reinforcement disc (null disc) were counted automatically.

The test condition (field vs. no field), total responses and total reinforcement for each disc were recorded. The distribution of responses for the first 20 pecks (before the first option for reward) as well as the percentage of correct responses on the reinforcing disc were recorded during each test session. The percentage of correct responses per day was obtained for each bird. A daily record of body weights was also maintained.

Discrimination Testing Procedure

Pigeons 747 and 743 were rewarded if they pecked the left disc when the rotating magnetic field (RMF) was present, whereas 728 and 670 were rewarded for pecking the right disc when the field was present. The first two birds were also rewarded for pecking the right disc when the field was not present. The second two birds were rewarded for pecking the left disc when no field was present. The turntable was left on during the no-field condition, since a slight humming noise was given off by the motor. Since the turntable was set at 45 rpm, the intensity of the field changed 45 times per minute with a peak to peak variation at pigeon head height of about 0.5 gauss (0.50-0.63) over the background steady state (0.45 G) field, as measured by a Gaussmeter (Model 750). Figure 2 shows the relative field intensity and displacement within the chamber using a power frequency field meter (Model 113-2). No steady state magnetic field associated with the operation of the feeder apparatus could be detected; light intensity in the chamber was 100 ± 3 lux.

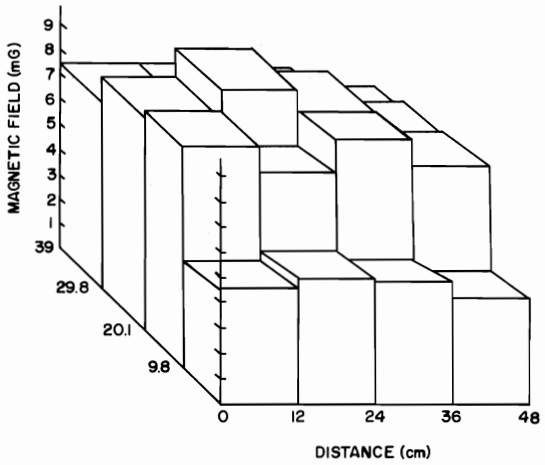

Figure 2. Three-dimensional plot of magnetic field strength and displacement against distance within the test chamber.

Because the birds were expected to associate the rewarding disc with spatial position more easily than with the presentation of changing magnetic fields, the daily presentation of test conditions (rotating magnetic field or no-field) was randomized. During the detection phase of each day's testing, the birds were exposed to the field or no-field condition for approximately 1 to 3 min before reward. If the animal selected the appropriate disc for the day, the detection portion of the experiment ended with the

first reward. Henceforth, the first reinforcement controlled the bird's behaviour. If the bird did not select the appropriate disc, responding could continue for several tens of displays, during which time the bird could still switch to the appropriate disc and deliver reward after 20 pecks. Consequently, the true measure of detection would be reflected in the first twenty responses. Except for the presence or absence of the field, the birds were not able to determine through anticipatory learning or contingent reward which disc was correct.

Calculations

The proportion of correct responses was calculated for each bird for each test day using the first twenty disc presses. Thus if disc A was the reinforcing disc on day one, the bird was required to press the appropriate disc 20 times to obtain a score of 100 percent. If the bird pressed the reinforcing disc six times and the null disc 14 times then the score was 30 percent. By plotting the proportion of correct responses over consecutive test days, we could determine whether learning had taken place.

Because several authors have reported that the primary sun compass may override magnetic field cues to homing pigeons (7, 11), we conducted discrimination testing under both light and dark. For the light condition, the normal fluorescent lighting within the room was used. Under dark conditions, the room lights were turned off before the subject was introduced into the test room and remained off throughout the test period. The only light present within the test chamber was that resulting from the dim disc lights.

Analysis

Scattergrams were plotted of the proportions of correct responses and sessions for each of the three light and three dark phases per bird. Spearman's r_s as well as Pearson's r were calculated for each sequence. Light phase one lasted 26 days, dark phase one lasted 33 days. Light phase two lasted 18 days whereas the other three phases lasted 14 days each. All analyses were completed with SPSS software on a DEC2020 computer. Although group analyses were considered inappropriate considering the expected individual differences, MANOVA (multivariate analysis of variance) was conducted according to Field Presence (yes, no), Phase (light vs dark) and Presentation (1st, 2nd, 3rd) to verify objectively a lack of group effect. The mean percentages of correct responses for the middle six days of each phase for each bird were used as indicators of discrimination.

Definitions

Several terms were utilized to define patterns observed in each of the scattergrams. To facilitate the evaluation of the overall experiment as well as each phase, some important terms were developed. They are as follows:

1. *Key preference responding* was applied to birds that consistently showed zero and 100 percent scores. If a pigeon showed a disc preference, this type of response might be expected.

2. *Habituation behaviour* was shown when responding dropped from a high rate of accuracy to a low or zero rate of accuracy.

3. *Random responding* was defined as an apparent indiscriminant responding on both discs with no pronounced degree of accuracy.

4. *Lever drift* referred to the tendency for a bird to shift gradually from high accuracy on one disc to high accuracy on the other disc with the associated drop in accuracy for the other disc.

5. *Maximum discrimination* was observed when accuracy was achieved on both discs under random daily conditions of field or no field.

Logical Statements

1. Partial discrimination of the rotating magnetic field was implied if:

   a. performance on the magnetic field disc was high or low with no change in performance on the null disc; or

   b. performance on the null disc was high or low with no change in the magnetic field disc performance.

2. If performance on both the magnetic and null field discs were high or low, full discrimination was implied.

3. If magnetic field disc performance was extremely high and null disc performance was extremely low (or the reverse), a drift towards disc preference had occurred and discrimination was not implied.

These logical statements were applied to the entire experiment and separately to each of the light and dark phases in order to determine possible phase contributions.

Results

A group analysis of variance involving light versus dark phases and presentation (1st, 2nd, 3rd) for all four birds

demonstrated no statistically significant differences between presence or absence of field, phase or presentation (F<1.00). However, a phase by field presence interaction approached significance (F=2.68; df=1,3; P=0.20). The performance between the four birds individually was significant (F=575.93, df=1,3; P<.001). This suggested that analyses based on performances of individual subjects were more appropriate.

Pigeon 747

During light phase two, pigeon 747 showed weak overall learning (Figure 3). A weak positive trend (r_s=0.31; P<0.12) was seen in the overall run of 18 days. Pigeon 747 showed strong learning (r_s=0.75; P<0.010) over trials for the disc that was associated with the magnetic field. Response accuracy to the reference disc showed no significant change (r_s=0.13; P>0.05) over time.

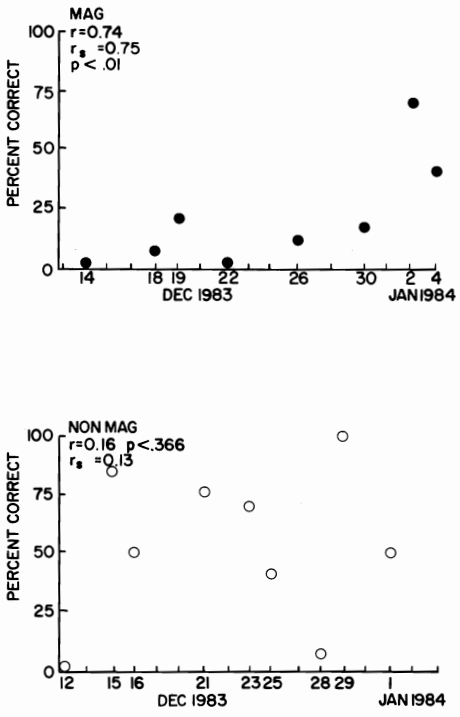

Figure 3. Proportion of correct responses for light phase two (pigeon 747) showing performance on magnetic (closed circle) and non-magnetic (open circle) days.

A significant positive correlation between the percentage of correct responses and the number of exposures to the field condition over time occurred. This suggests that learning or detection of the magnetic field was in progress. However, no significant correlation between accuracy and time occurred for non-magnetic field days. This suggest that there was no learning or detection of the non-magnetic field condition.

During dark phase two, this bird showed the best performance of all birds tested. One hundred percent accuracy was scored on five successive days. Of these five days, two were on RMF days and three were on control days (Figure 4). This high level of performance persisted even though there had been a rest day in the middle of the series. RMF presentations considered alone showed no statistically significant effect (r_s=0.09; P<0.20). There was a slight positive trend (r_s=0.48; P<0.10) during the control days.

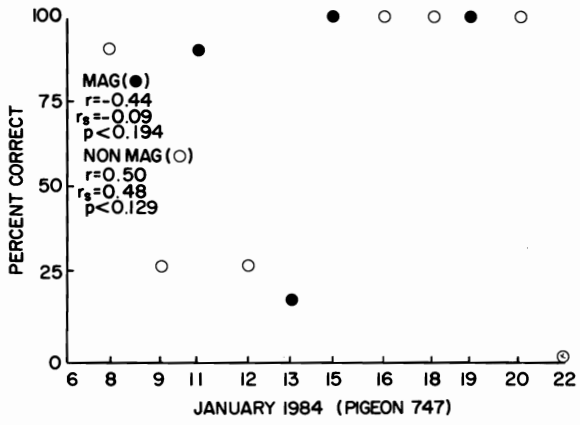

Figure 4. Proportion of correct responses for dark phase two (pigeon 747) showing performance on magnetic (●) and non-magnetic (O) days.

The negative coefficient for the magnetic condition may be due to one point. Note the consistent scores from the 15th to the 20th. There were two disc switches during this time.

This plot showed the strongest learning behaviour for all birds during all phases. A run on of this performance carried over into the next phase (see Figure 5).

In light phase three, pigeon 747 showed clear learning again (Figure 5). The overall run showed a positive correlation (r_s=0.47; P<0.05). Days of RMF, presentations showed a non-significant positive correlation (r_s=0.14; P<0.05). The control days showed a strong positive correlation (r_s=0.85; P<0.05). The high degree of accuracy by the end of this run extended into dark phase three. In

dark phase three pigeon 747 showed an overall tendency to extinguish. Lever drift accuracy was shown (RMF paired disc: r_s=-0.88; P<0.04; control paired disc: r_s=0.39; P<0.20).

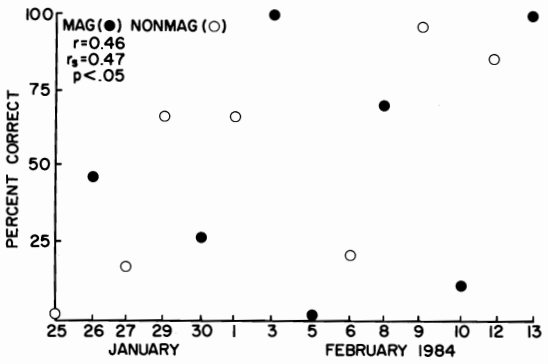

Figure 5. Proportion of correct reponses for light phase three (pigeon 747) showing performance on magnetic (●) and non- magnetic (O) days.

Pigeon 743

Pigeon 743 showed key preference responding for light phase one, dark phase one and dark phase two. This bird habituated in dark phase three with an overall negative correlation between accuracy and trials (r_s=0.49; P<0.04).

Pigeon 728

Lever drift appeared to dominate responding during testing by 728 in the first light phase. The first dark phase showed no significant correlations. When the individual components were analyzed separately, lever drift followed by random responding was noted. Accuracy on control days showed a consistent negative correlation during the first half of the run, then leveled off in the mid-percentiles (r_s=-0.31; P<0.10). Accuracy for the magnetic component increased with time (r_s=0.42; P<0.05) during the first half of the run.

The first dark phase was further analyzed because a large segment within the centre of the run displayed the characteristics of a learning curve. The central 18 days (Figure 6) showed a significant positive correlation (r_s=0.53; P<0.01).

Pigeon 670

Key preference responding dominated the phases. In dark phase two, however, the first signs of weak learning were seen. During the first five days of the run, the bird showed learning behaviour with a significant positive correlation between accuracy and trials (r_s=0.80; P<0.05). Response accuracy during the next eight days showed a strong negative correlation with time (r_s=0.68; P<0.03) indicating that pigeon 670 had habituated.

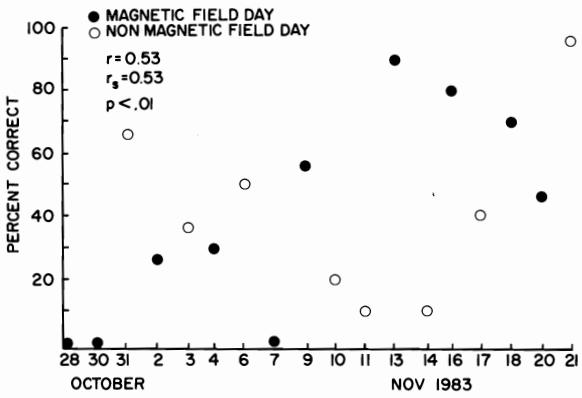

Figure 6. Dark phase one showing the percentage accuracy of condition (field/no field) over time for bird 728.

Discussion

There were several instances where each bird demonstrated response patterns that were commensurate with a learning profile. Differential discrimination and response accuracy for both the RMF and control days were particularly evident for pigeon 747. In each case the propensity for learning even when it was weak appeared to require a long period of testing. Learning is technically defined as more or less a permanent change in behaviour due to experience. In this instance, a clear learning profile was evident within different phases of the experiments. However, these patterns disappeared when sudden changes in ambient lighting during testing (the phases) were instituted. This would suggest that the learning was very weak and easily disrupted by environmental factors. Alternatively, if RMF detection is sensitive to the conditions of state dependent memory of context specific learning, the successive changes in situational cues may have prevented the well learned responses from occurring.

Although the magnitude of the effect was weak and perhaps even probationary by some experimental standards, the general profiles indicate that some learning occurred in

some birds. The double disc discrimination task appears to be very difficult for pigeons and susceptible to the types of complications that often accompany difficult discriminations. Half of the birds adopted key preference or stereotyped patterns of responding that indicated the problem (field vs no field discrimination) was insoluble. All of the birds showed habituation during at least one phase of the study.

In mammals, insoluble problems (within the perceptual or cognitive capacity of the animal) are frequently indicated by stereotyped, preference response profiles that are relatively resistant to modification, even when the problem becomes soluble (5). It would be interesting to determine whether those birds that did show some evidence of discrimination have more appropriate sensory perception or learning capacity than the birds that showed little hint of discrimination. Perhaps this factor is involved with the well known individual variability in responses and problems in inter-laboratory replication of studies of magnetic field discrimination studies.

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